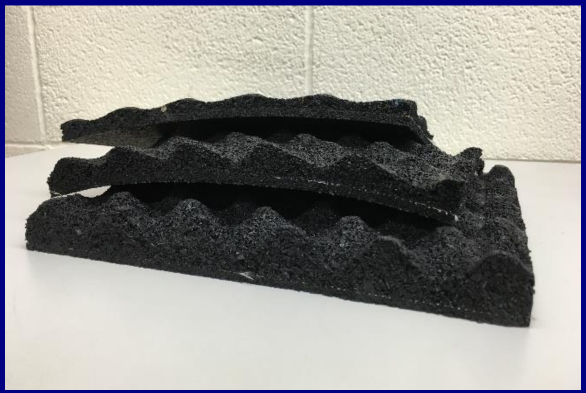
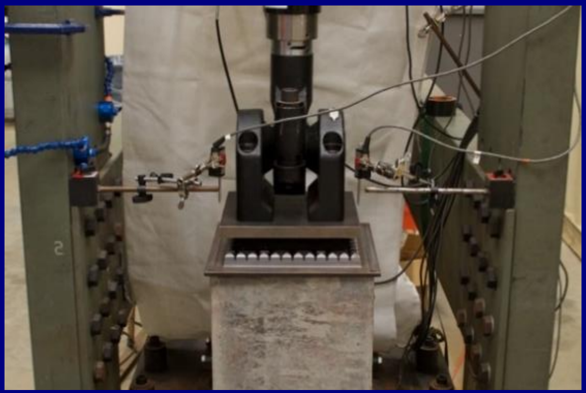
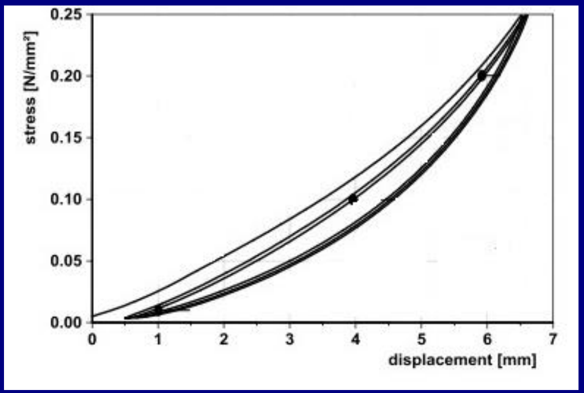
Laboratory Study into the Effect of Support Condition on Ballast Mat Bedding Modulus and Insertion Loss







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RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Progress Rail
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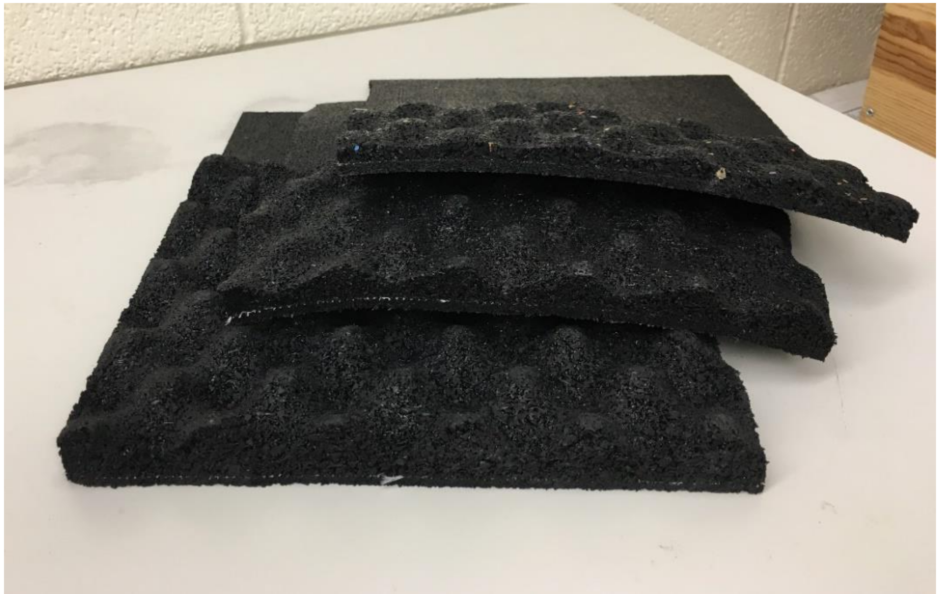
Outline

- Introduction
- Background and Motivation
- Goals for Research
- Laboratory Experiment Program
- Results from Laboratory Tests
- Statistical Analysis
- Prediction Model
- Conclusions
- Future Work

Introduction

- Ballast mats (under-ballast mats) are elastic pads installed under the ballast layer or concrete slab, depending on the type of track structure
- Typically manufactured using natural rubber, recycled tire rubber, or EPDM synthetic rubber



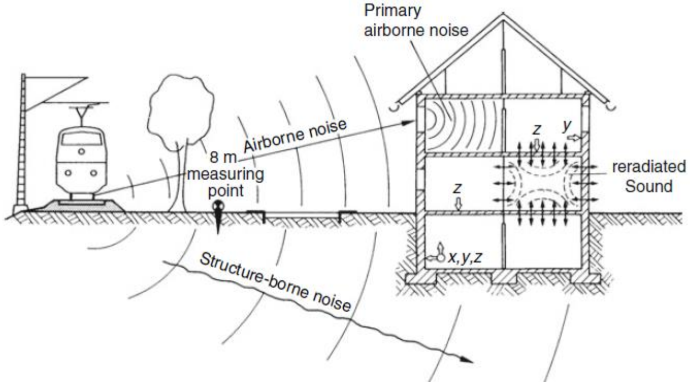
Mademann, C. and D. Otter. 2013. *Effects Of Ballast Depth And Degradation On Stresses In Concrete Bridges*. Transportation Technology Center, Inc.

Background and Motivation

- The study of ballast mats were started in the 1960's by the Japanese Railways for use in the Tokaido Shinkansen line
- European passenger and freight services have also used/studied ballast mats since early 1980's
- North America, Class I railroads have primarily used ballast mats on ballast deck bridges and tunnels with limited research being conducted to date
- Globally, the German DIN 45673-5 is the only standardized testing procedure available for determining component properties of ballast mats
- The growing interest in North America for this component has established a demand for the development of uniform and representative testing procedures

Goals for Research

- Major benefits from the use of ballast mats are dependent on its application environment:
  - Transit: reduction of ground-borne noise and vibrations
  - Freight: reduction of ballast degradation and track stiffness in transition zones
- The main objectives of this research are to:
  - Quantify ballast mat properties
  - Quantify ballast mat benefits
  - Study the effect of test variables (support, loading, etc.)



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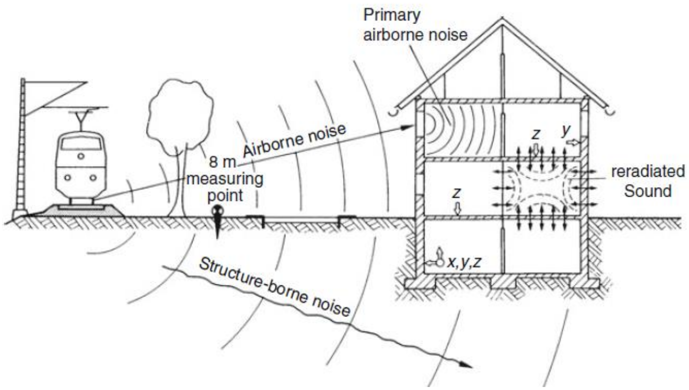

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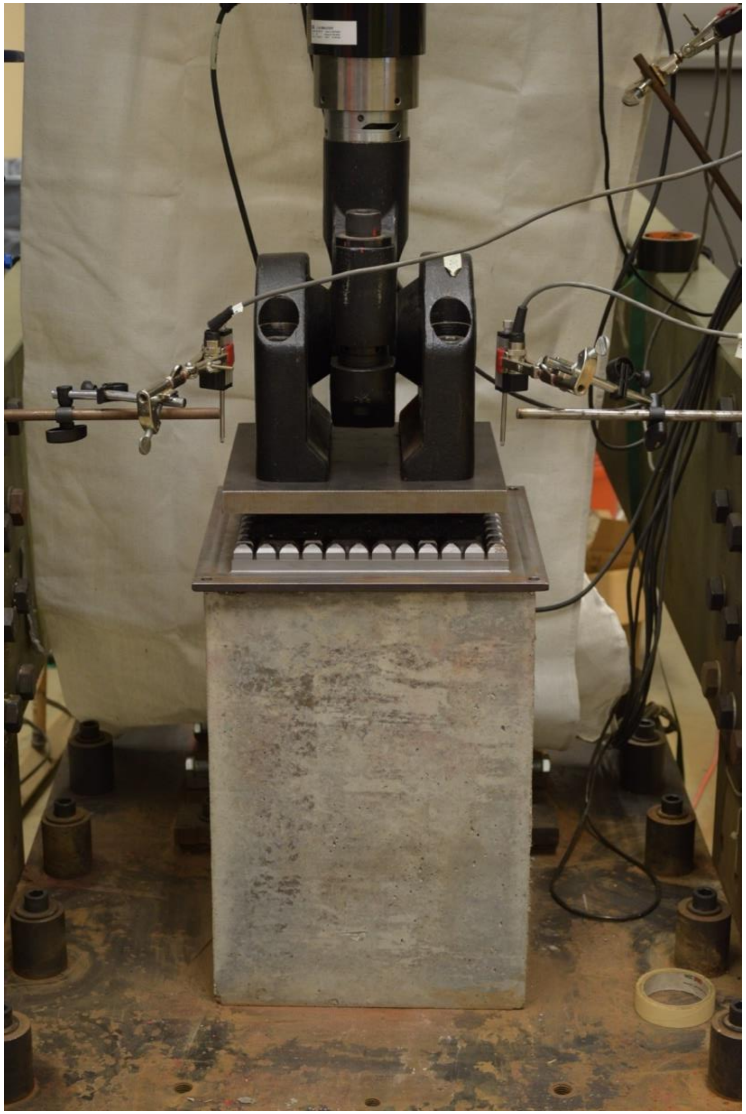
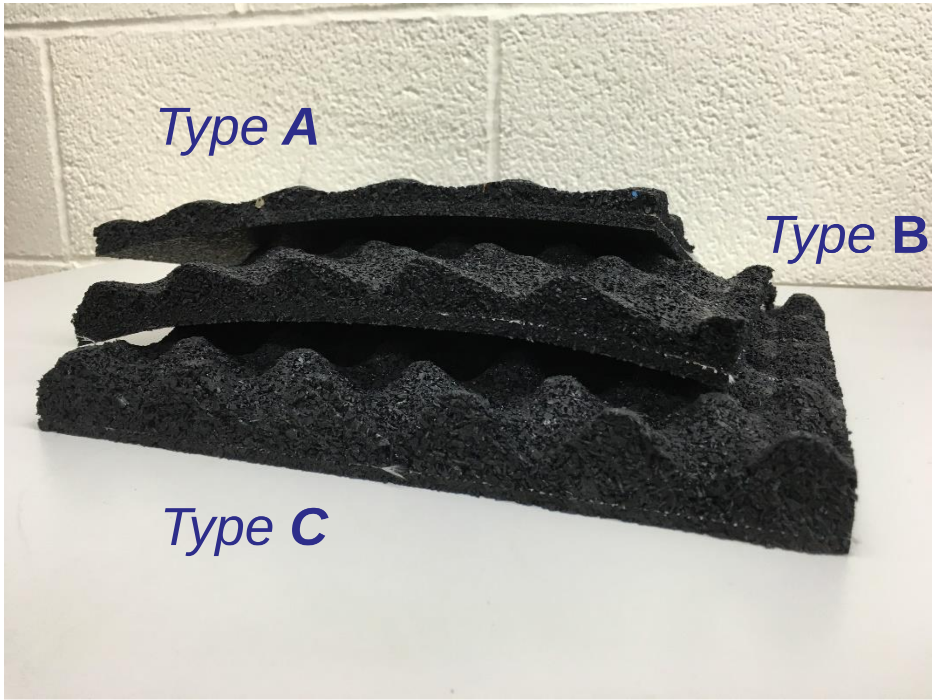
Laboratory Experiment Program

- **Objective:** To determine component properties of ballast mats in controlled laboratory setting using various support conditions
- **Location:** Research and Innovation Laboratory (RAIL) at Schnabel, UIUC
  - Pulsating Load Testing Machine (PLTM):
    A biaxial loading frame owned by Progress Rail able to simulate various L/V force ratios
- **Instrumentation:** Potentiometers deployed to capture vertical ballast mat displacement at multiple locations
- **Loading:** servo hydraulic actuator used to apply vertical load to ballast mat



Ballast Mat Sample Types



- Ballast mat samples
  - Size : 10” x 10” (254 x 254 mm)
  - Thickness (Min / Max)
    - Type A:
      - 0.197” / 0.394” (5/10 mm)
    - Type B:
      - 0.315” / 0.670” (8/17 mm)
    - Type C:
      - 0.275” / 0.984” (7/25 mm)

Support Conditions

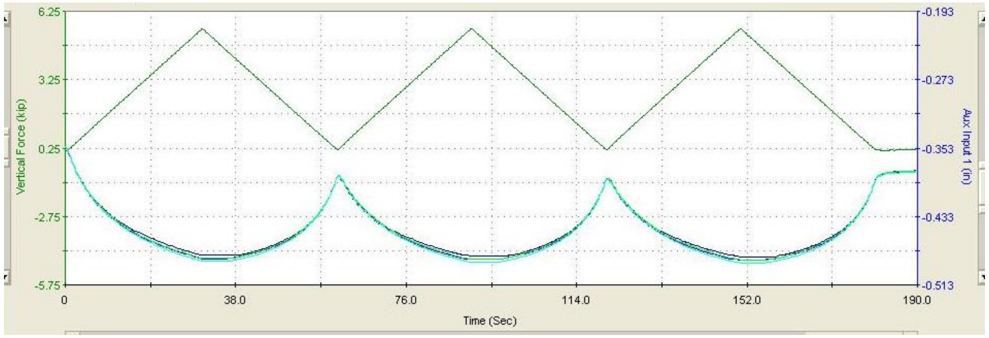
- **Geometric Ballast Plate (GBP)**
  - Standardized European apparatus (EN 16730:2016)
  - 12” x 12” (300 x 300 mm) aluminum profiled plate that simulates ballast profile
- **Concrete**
  - 14” x 14” (356 x 356 mm) Concrete block
- **Steel**
  - 12” x 12” (305 x 305 mm) Steel plate placed over concrete block

Important Definitions

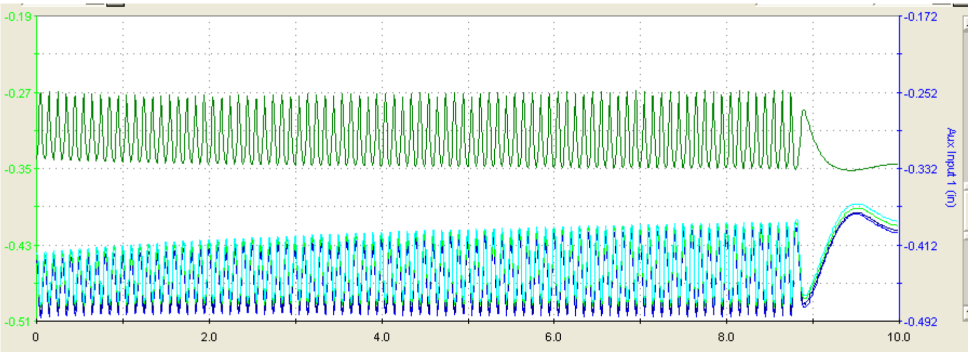
- **Bedding Modulus:**
  - The amount of force required to cause unit deflection in a unit area sample (lbs/in^3 or N/mm^3)
    - Static
    - Dynamic
- **Insertion Loss:**
  - Ratio of signal levels (vibration amplitudes) before and after the installation of a filter (i.e. ballast mat)
    - $\Delta L = 20 log\left(\frac{V_1}{V_2}\right)$

Bedding Modulus Test Protocol

- Procedure heavily based on German standard DIN 45673 – Part 5
- **Static Tests:**
  - Quasi-static
  - Load
    - 0.2 - 3.8 kips (0.9 – 16.9 kN)
    - 3 cycles
- **Dynamic Tests:**
  - Frequencies: 5 Hz and 10 Hz
  - Loading
    - 0.4 - 3.8 kips (1.8 – 16.9 kN)
  - 10 sec. of sinusoidal loading
  - Data collected for last 10 cycles

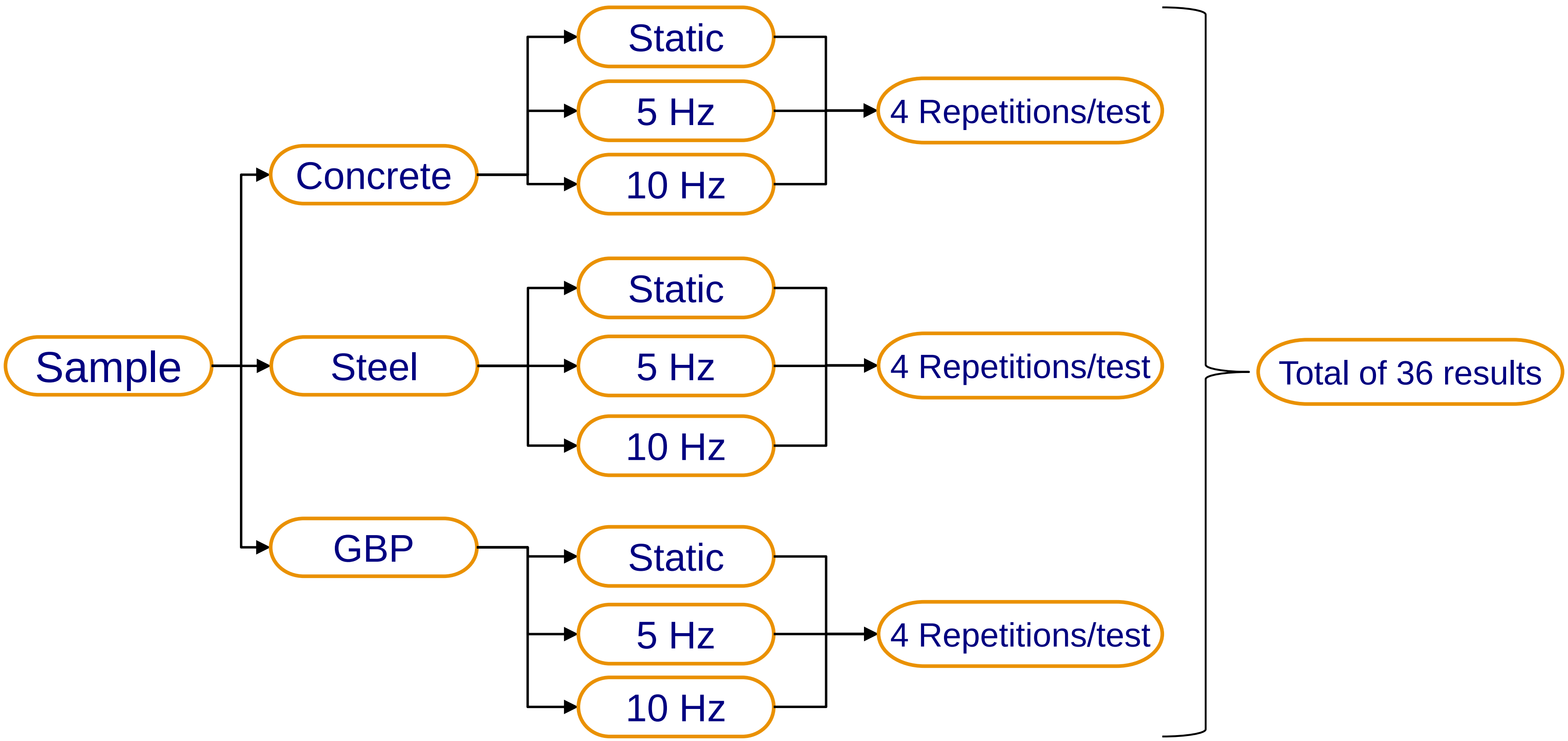


Static loading waveform (triangular) with associated displacement



Dynamic 10 Hz loading waveform with associated displacement

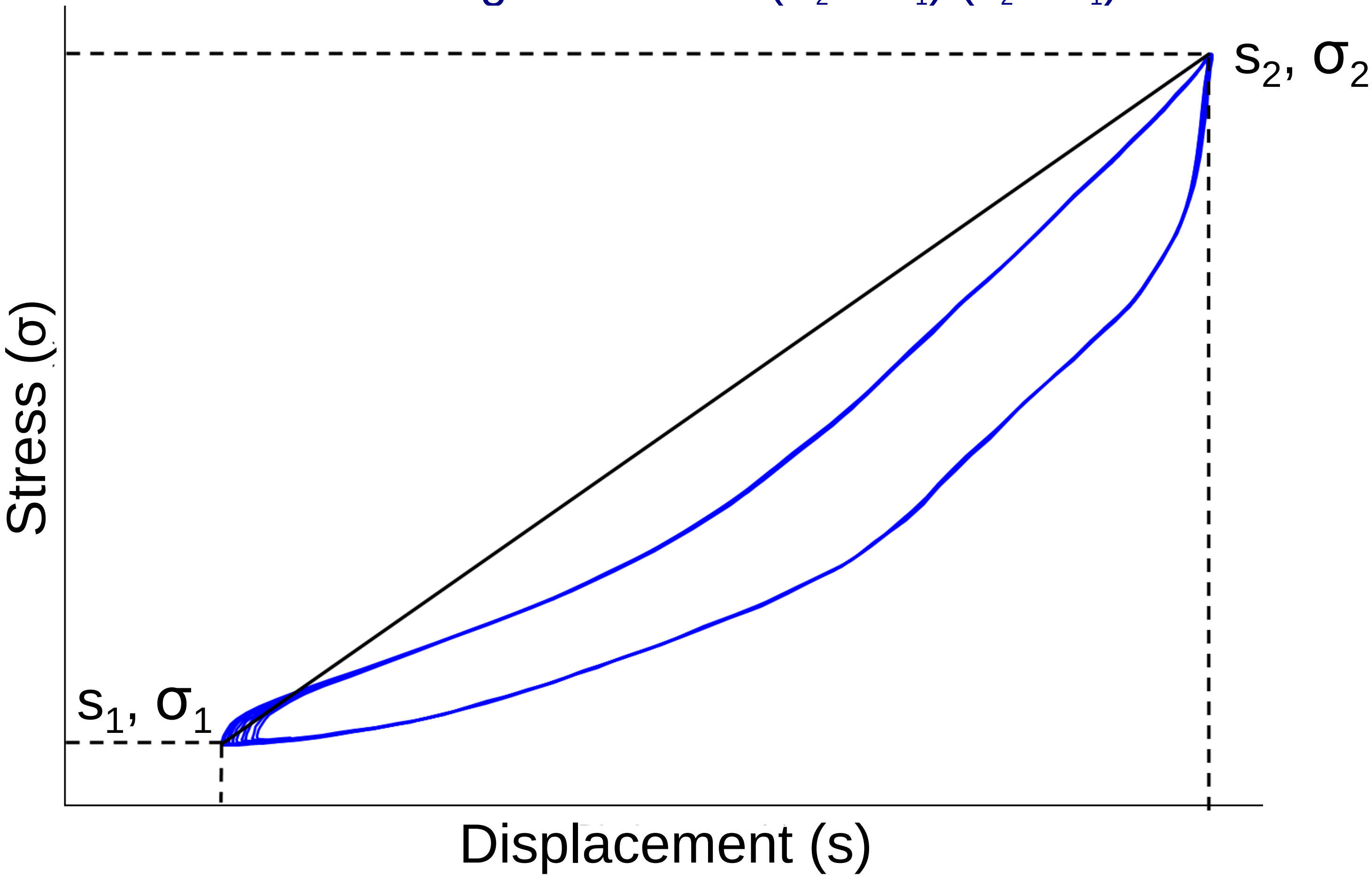
Laboratory Experimental Matrix



Results from Laboratory Tests
Bedding Modulus

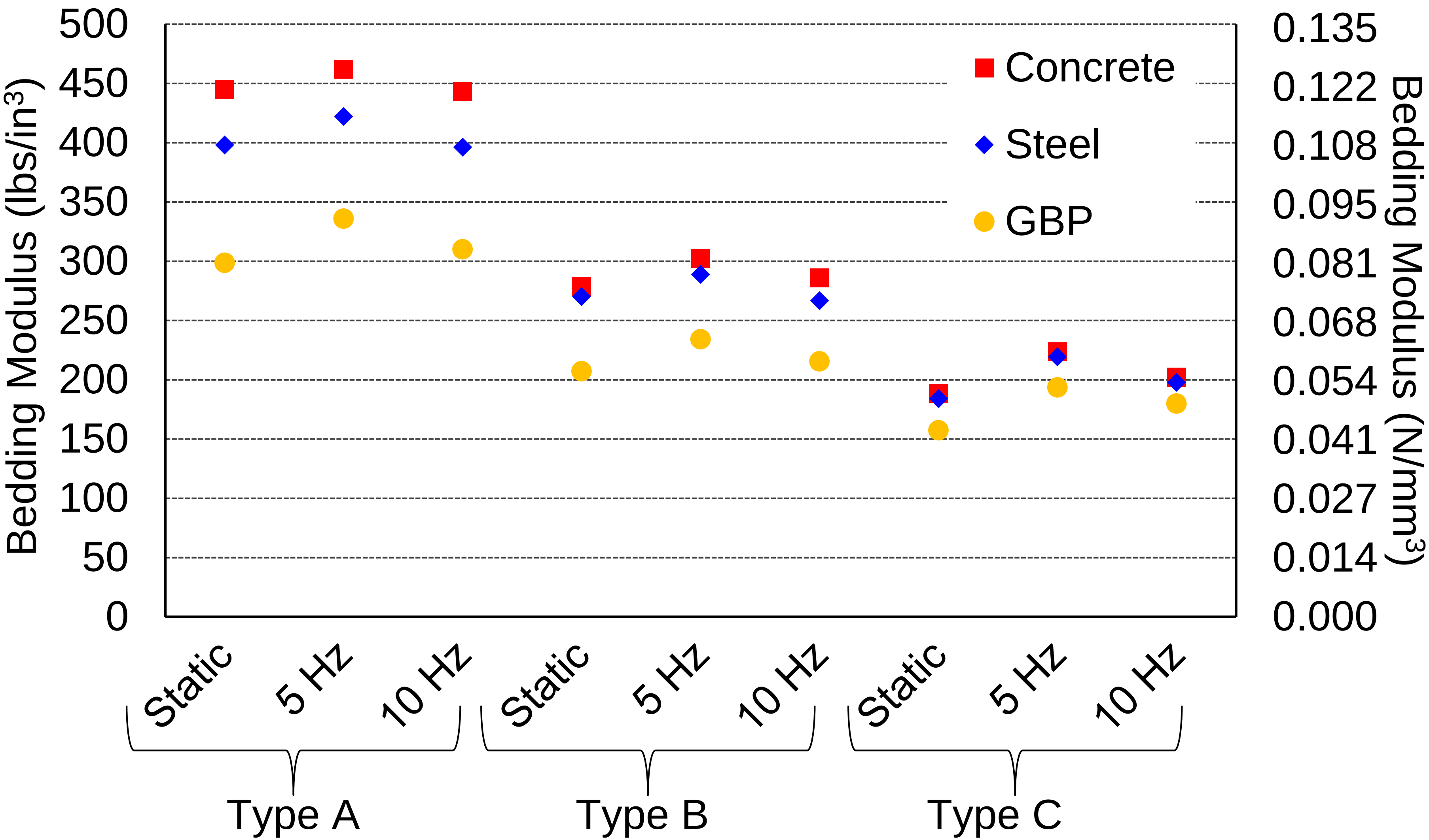
- Static and dynamic bedding modulus calculated using **secant modulus**

Secant Bedding Modulus = $(\sigma_2 - \sigma_1)/(s_2 - s_1)$



Results from Laboratory Tests

Summary of Bedding Modulus Tests



Results from Laboratory Tests

- Consistency of testing was supported by a maximum 4.0% deviation from the mean for a single test procedure
- Results obtained using the GBP were 30% and 21% lower than their corresponding tests conducted with concrete and steel support respectively
- Bedding modulus values obtained with concrete support as a support were highest for all cases
- Effects of different test frequencies could not be investigated due to uncertainties with the results obtained for higher frequencies (i.e. 10 Hz)

Statistical Analysis

- Analysis of variance (ANOVA) conducted in order to determine variability of the results obtained
  - Tukey's Studentized Range test chosen for mean separation analysis.
  - Factorial treatment was applied to each of the sample distributions with treatments:
    - Support Condition: 3 levels (Concrete, Steel & GBP)
    - Loading Type: 3 levels (Static, 5Hz & 10 Hz)
- Type I error rate (α) = 0.01
  - For all tests, ANOVA Model P-Value = <0.0001
- **Results from all support conditions were found to be statistically different**

Insertion Loss Prediction Model

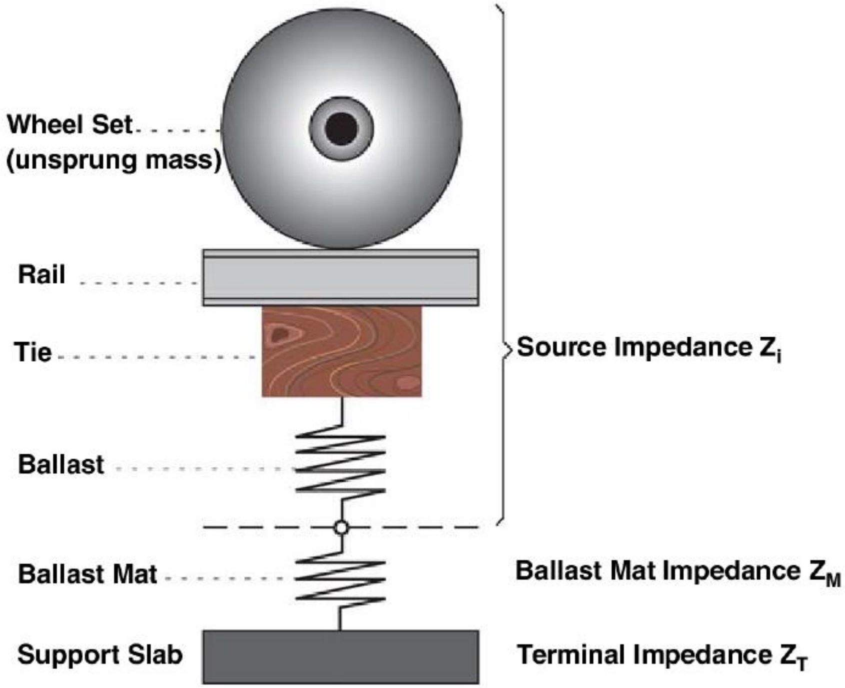
- To determine the predicted performance of these components, insertion loss was calculated based on bedding modulus values obtained
- *Model developed by Wettschureck & Kurze (W&K)* was chosen for yielding comparable results with field data available
- Inputs in the selected model include
  - Track structure characteristics
  - Loading environment
  - Ballast mat properties

B/M on reinforced concrete floor / reduced ballast

Configuration of superstructure				Pos.
Railtype:	AREA 136			1.
Type of sleeper:	concrete			2.
Ballast mat type:	USM 4000			3.
Floor:	B/M on reinforced concrete floor			4.
Data railway track				
E-Modulus, rail, E:	2,06E+05	[N/mm²]		5.
Moment of inertia, rail, I:	3,95E+07	[mm⁴]		6.
Section modulus, rail, W:	3,92E+05	[mm³]		7.
Weight/meter, rail, m_s:	67,56	[kg/m]		8.
Tie spacing, a_1:	0,61	[m]		9.
Width, tie, b_s:	0,27	[m]		10.
Length, tie, l_s:	2,60	[m]		11.
Outstanding, tie, ü:	0,55	[m]	0,55	12.
Mass, tie, m_s:	320,00	[kg]		13.
Spacing gauge, w:	1,435	[m]		14.
Height, ballast, h:	0,22	[m]		15.
Spec. gravity, ballast, ρ:	1,70E+03	[kg/m³]		16.
Bed moduli				
Bed modulus, ballast, C_{sch}:	5,00E-01	[N/mm³]		17.
Bed modulus, B/M, C_{stat}:	1,00E-01	[N/mm³]		18.
Bed modulus over all, $C_{stat,ges}$:	8,33E-02	[N/mm³]		19.
Cdyn, floor, C_{grd}:	0,35	[N/mm³]		20.
Cdyn. B/M, C_{dyn}:	0,179	[N/mm³]		21.
Approx. load range, σ_1:	0,072	[MPa]		22.
Damping, D:	0,35	[ ]		23.
Geometry of track				
Straight line: (0), Curve: (1)	0	[ ]		24.
Quality of track, n: 0,1(+); 0,15 (0); 0,2 (-); 0,25 (--)	0,1	[ ]		25.
Dynamic force Factor, k_{dyn}:	1,31	[ ]		26.
Car type, freight: (1), passenger: (2)	1	[ ]		27.
Nominal axle load, Q:	363	[kN]	475	28.
Spacing between axles (bogie), a_2:	2,40	[m]		29.
Max. speed, v:	65	[km/h]		30.
Centre spacing bogies, a_3:	10,00	[m]		31.

Insertion Loss Prediction Model

- W&K theoretical model
  - One-dimensional
  - Single degree-of-freedom
  - Insertion loss obtained from three mechanical impedance values:
    - Source (Z_i)
    - Ballast Mat (Z_M)
    - Terminal (Z_T)
  - All impedance values are represented as complex numbers to account for the effect of damping

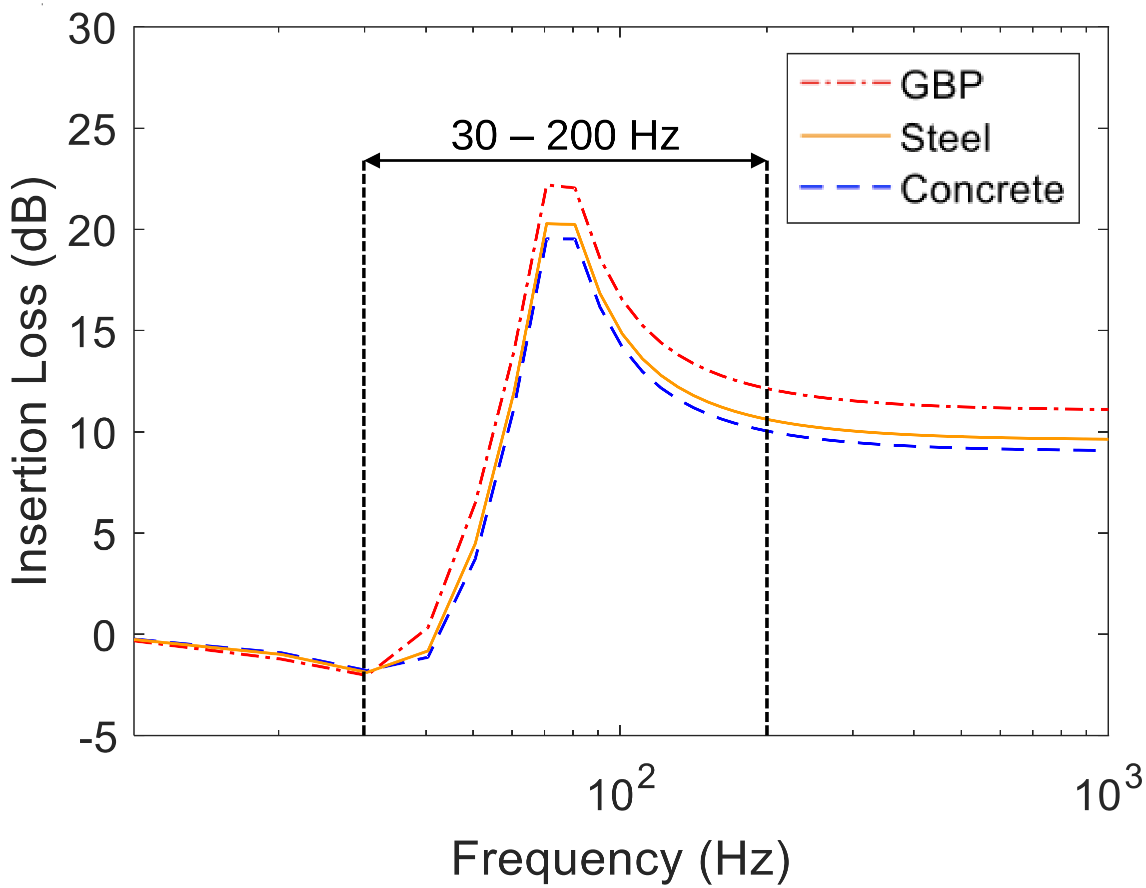


$$\Delta L = 20 \log \left[\frac{\dfrac{1}{1/Z_i + 1/Z_T}}{\dfrac{1}{1/Z_i + 1/Z_T + 1/Z_M}} \right]$$

$\leftrightarrow$ V_1 (before)

$\leftrightarrow$ V_2 (after)

Insertion Loss Prediction – *Sample A at 5 Hz*



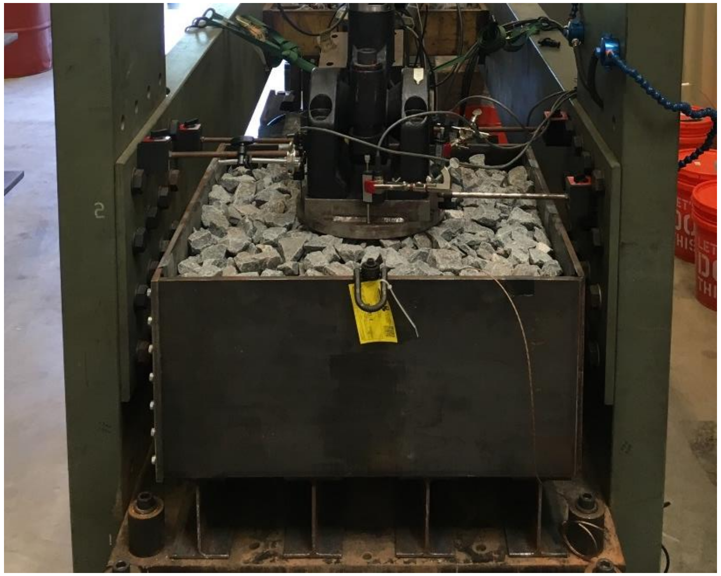
- GBP support condition (lower bedding modulus) consistently yields higher insertion loss for frequencies above 30 Hz, but it is most influenced at the peak insertion loss frequencies

Conclusions

- The bedding moduli of a ballast mat is dependent on the support condition with which it is tested
  - GBP typically resulted in lowest values
  - Steel and Concrete yielded similar values
- The statistical analysis of the results corroborated the visual analysis of the results as to the difference between the bedding modulus values obtained from each support condition
- Sensitivity analysis provided a better understanding of the importance of standardizing the support condition used to obtain the dynamic bedding modulus values to be input in the prediction models
  - Maximum insertion loss difference between all support conditions of:
    - 3.0 dB for Type A
    - 2.4 dB for Type B
    - 1.2 dB for Type C

Future Work

- Mechanical fatigue strength tests
  - Ensure survivability
    - Comparison of bedding modulus before and after repeated load cycles
  - Quantify effect on ballast deterioration
    - Gradation
    - Ballast surface characteristics
    - Ballast geometry
  - Quantifying ballast mat's effects to the vertical transient deformations of a ballast structure over a rigid support
- Investigation into the impacts and viability of using the GBP setup as a substitute for the ballast box mechanical fatigue testing of ballast mats



Acknowledgements

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Thank You

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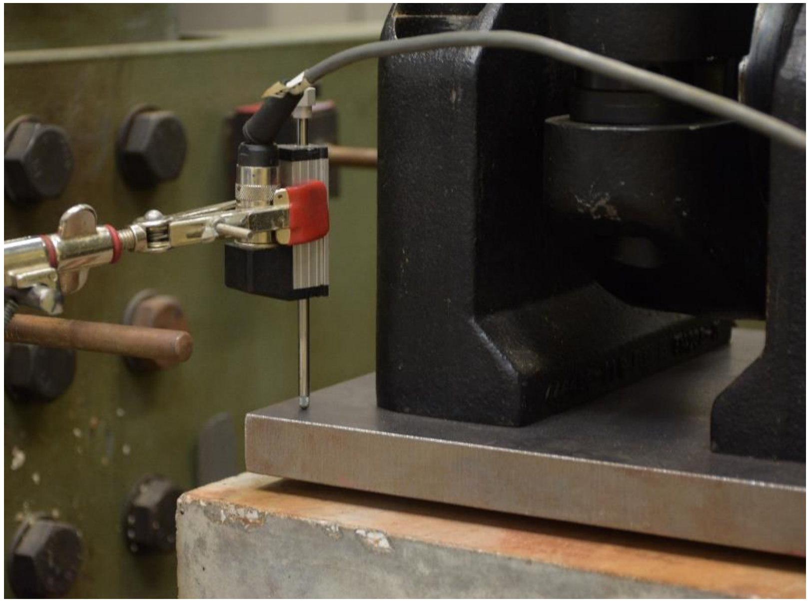

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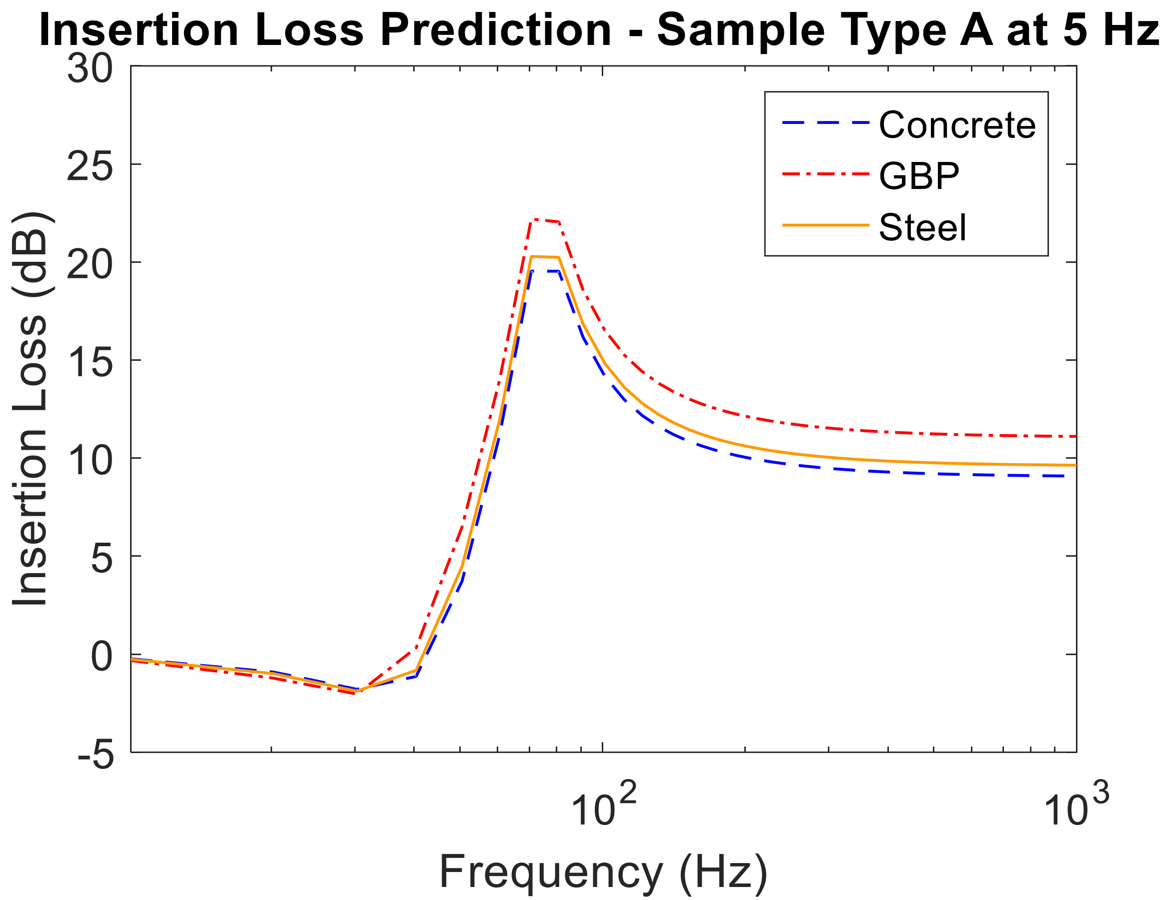
Appendix

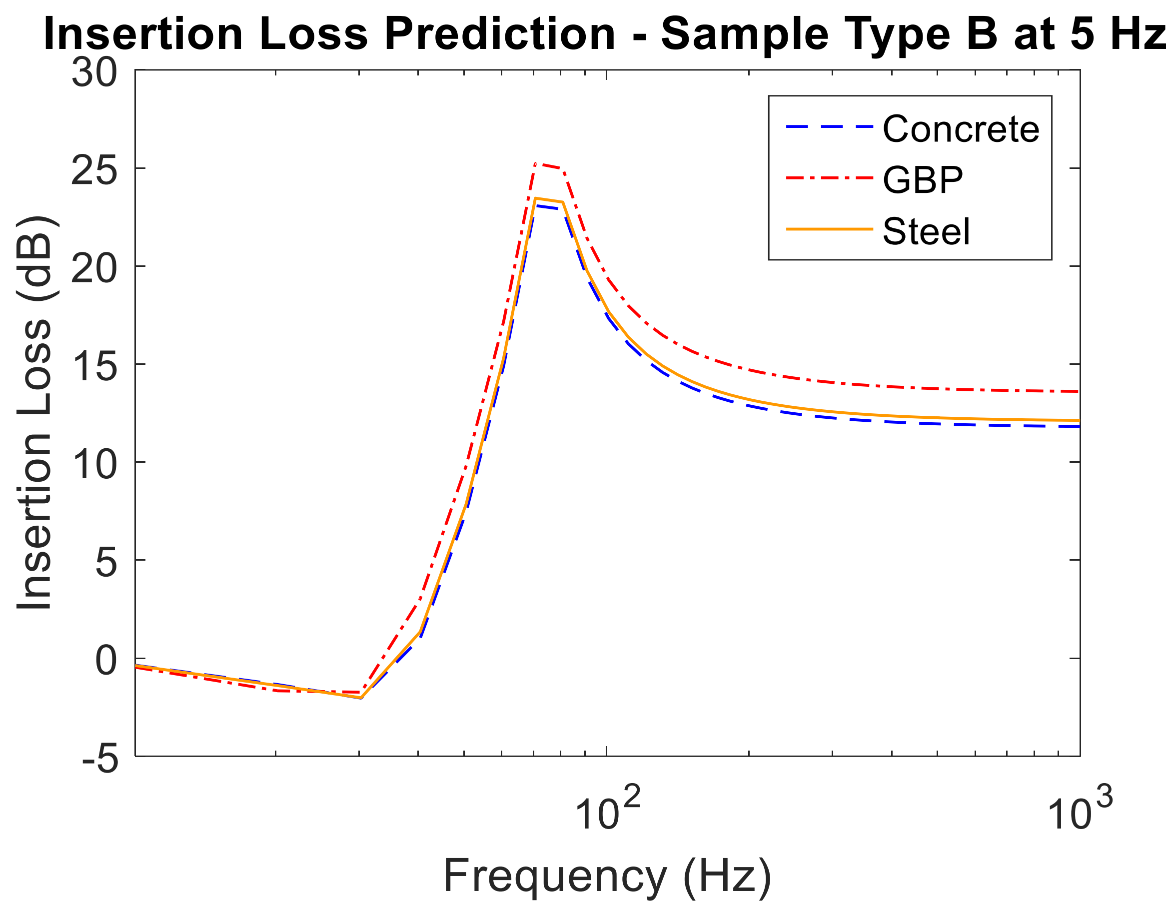
Statistical Analysis Summary of Results

Grouping	Mean	Support Condition	Grouping	Mean	Loading Type
Type A					
A	449.964	Concrete	**A**	406.745	Static
B	405.504	Steel	**B**	383.19	Dynamic 5 Hz
C	314.918	GBP	**B**	380.451	Dynamic 10 Hz
Type B					
A	288.869	Concrete	**A**	275.14	Static
B	275.268	Steel	**B**	256.067	Dynamic 5 Hz
C	219.042	GBP	**B**	251.971	Dynamic 10 Hz
Type C					
A	204.71	Concrete	**A**	212.232	Static
B	200.422	Steel	**B**	193.306	Dynamic 5 Hz
C	176.956	GBP	**C**	176.551	Dynamic 10 Hz

Sensitivity Analysis
Type A Sample



Sensitivity Analysis
Type B Sample



Sensitivity Analysis
Type C Sample